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Four element linear array of annular slot antenna under superstrate cover

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Abstract : An annular slot array of four elements has been investigated with low dielectric base and a high superstrate cover. The far-zone field patterns are obtained using vector wave function approach and analytical technique of microstrip antennas. The field patterns are computed and plotted for two modes in free space. Other antenna parameters like half power beamwidth (HPBW), radiation conductance and directivity are also computed. The results are interesting and the antenna geometry is suitable for application in mobile communication systems.

Keywords : Microstrip antenna array, superstrate cover, radiation properties

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1. Introduction

In recent years, microstrip antenna technology has attracted the attention of different workers due to its potential application. Obviously, in satellite communication, radar and missile etc., antenna arrays show better radiation performance over the single element antennas. Microstrip array antennas are being used in mobile communication system [1-3]. Microstrip slot antennas and arrays find favourable applicability in mobile communication systems due to its advantage of preventing spurious radiations arising from the substrate edges due to diffraction [4].

Microstrip antennas employed in mobile communication systems require superstrate cover over the radiating surface to provide protection against heat, physical damage and the environment. It also increases the power handling capability of antenna system [5-6]. In present communication, a four element linear array of annular slot has been investigated with alumina cover superstrate. The properties like field patterns, radiation conductance, HPBW and directivity have been computed in X-band of microwave frequency range.

2. Method of analysis

The geometry and coordinate system of array antenna under investigation are shown in Figure 1.

It consists of four identical antenna slots on a dielectric substrate of height h_d, substrate permittivity $\varepsilon_d = 2.33$ (teflon) backed by a ground plane. The elements are uniformly separated

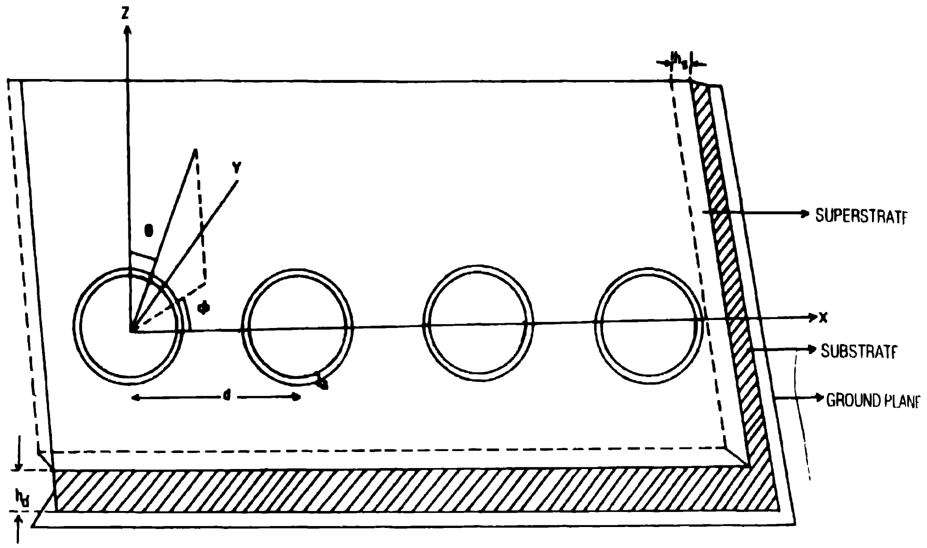

Figure 1. Geometry and coordinate system of four element annular slot microstrip linear array antenna.

by a distance d. An alumina superstrate of height h_s and permittivity $\varepsilon_s = 10.4$ is used to cover the radiating surface of the geometry. In such case, the composite dielectric constant ε_r caused by superstrate is given as [7]

$$\varepsilon_r = (\varepsilon_s \, \varepsilon_d [h_d + h_s]) / (\varepsilon_s \, h_d + \varepsilon_d h_s) \tag{1}$$

and the radius is

$$a = \lambda_0 / \pi(\varepsilon_r)^{1/2} \tag{2}$$

The far-zone field expression of the present geometry are obtained by the fields of a single slot antenna positioned at the origin multiplied by a factor called the array factor (A.F.), which is calculated following ref. [8] and is given as

$$A.F. = 4 \cos (kd \cos \theta + \beta) \cos ((kd \cos \theta + \beta)/2),$$

then the far-zone field expression of the array are obtained and are given as

$$E_{\theta t} = -j^n \frac{a\, k_0 E_0 W_s}{2} \frac{e^{-jk_0 r}}{r} \cos n\phi \, J_n'(a\overline{k_0} \sin \phi)$$
$$\times 4 \cos (kd \cos \theta + \beta) \cos ((kd \cos \theta + \beta)/2) \tag{3}$$

and

$$E_{\phi t} = j^n \frac{nE_0 W_s}{2} \frac{e^{-jk_0 r}}{r} \sin n\phi \cot \theta \, J_n(ak_0 \sin \theta)$$
$$\times 4 \cos (kd \cos \theta + \beta) \cos ((kd \cos \theta + \beta)/2) \tag{4}$$

The total field patterns $R(\theta, \phi)$ of the geometry is written as

$$R(\theta,\phi) = \left|E_{\theta t}\right|^2 + \left|E_{\phi t}\right|^2 \tag{5}$$

The radiation conductance of the antenna is obtained as

$$G = 2P/V_0^2, \tag{6}$$

where P is the average radiated power of the array antenna and is equal to

$$P = \frac{4V_0^2 W_s^2}{h_d} \int_0^{2\pi}\int_0^{\pi} I \sin\theta \, d\theta \, d\phi, \tag{7}$$

where I is given as

$$I = \cos^2 (kd\cos\theta + \beta) \cos^2 ((kd\cos\theta + \beta)/2)$$
$$\times [(ak_0)^2 \cos^2 n\phi \, J'^2_n (ak_0 \sin\theta) + n^2 \sin^2 n\phi \cot^2\theta J^2_n (ak_0 \sin\theta)]. \tag{8}$$

The directive gain of an antenna in a given direction is defined as the radiation intensity in the direction to the average radiated power [3] and is given by

$$D_g = \frac{4\pi M_e}{\int_0^{2\pi}\int_0^{\pi} M_e \sin\theta \, d\theta \, d\phi}, (\theta = 3\pi/4, \phi = 0), \tag{9}$$

where

$$M_e = \cos^2 (kd\cos\theta + \beta) \cos^2 ((kd\cos\theta + \beta)/2)$$
$$\times [(ak_0)^2 \cos^2 n\phi \, J'^2_n (ak_0 \sin\theta) + n^2 \sin^2 n\phi \cot^2\theta J^2_n (ak_0 \sin\theta)]. \tag{10}$$

3. Results and discussion

We have computed different radiation properties of linear array of annular slot antenna with alumina superstrate at 10 GHz. The other input parameters are $\varepsilon_s = 10.4$, $\varepsilon_d = 2.33$, $h_d = 1.58$ mm,

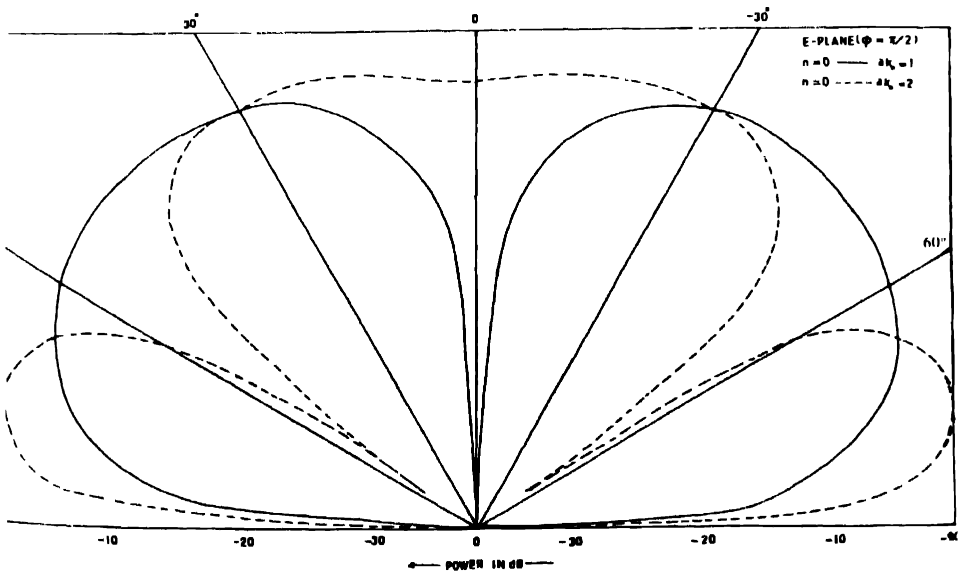

Figure 2. Field pattern for $ak_0 = 1$ and $n = 0$.

h_s = 0.6 mm. The computation has been made for two values of n *i.e.* $n = 0$ and 1 for two principle planes $\phi = 0$ and $\phi = \pi/2$ in two modes $ak_0 = 1$ and $ak_0 = 2$. The field patterns are shown in Figures 2-4.

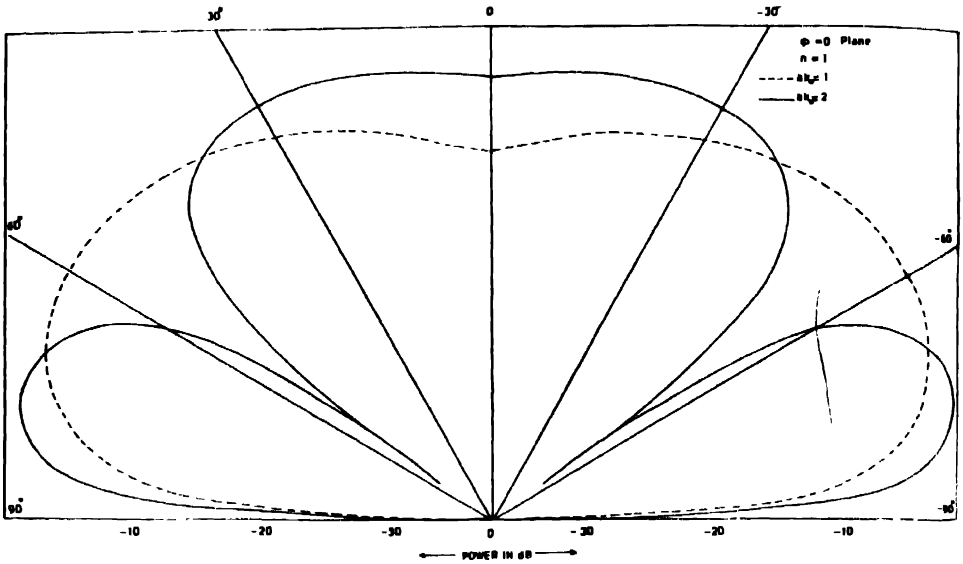

Figure 3 $\phi = 0$ plane field pattern for $n = 0$ and $ak_0 = 1$ and 2

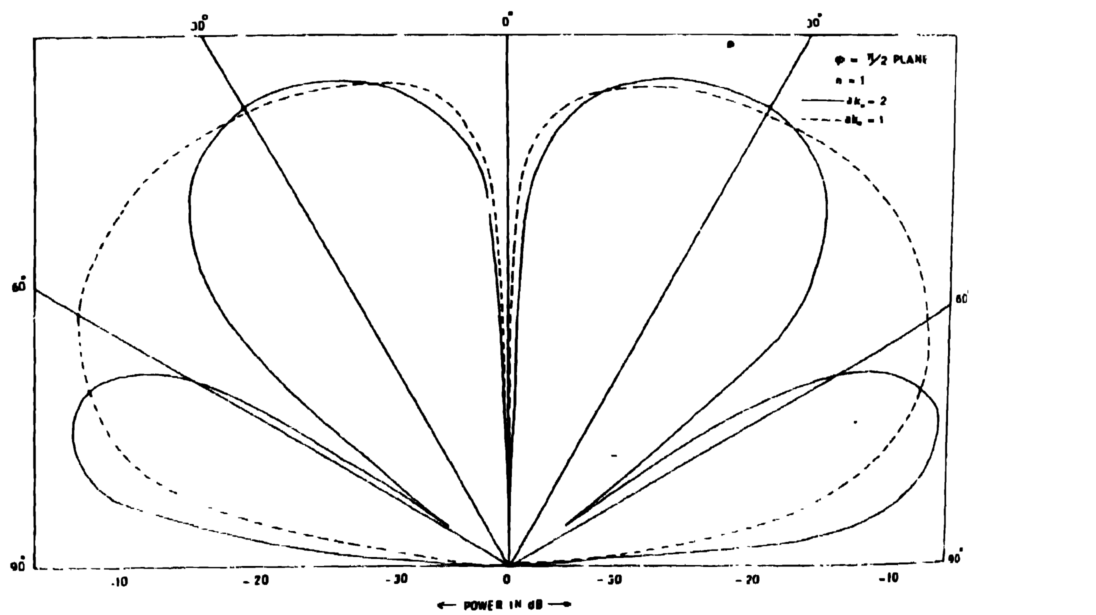

Figure 4. $\phi = \pi/2$ plane field pattern for $n = 1$ and $ak_0 = 1$ and 2.

For the case of $n = 0$ and $ak_0 = 1$, the pattern shows two lobes having maximum radiation in +45° and – 45°. For $ak_0 = 2$ there are three lobes out of which major lobe is of wide beam width and relatively small dip at 0°. The other two lobes are of narrow beam width and have maximum intensity at +75° and –75°. In case of $n = 1$, $\phi = \pi/2$ plane for $ak_0 = 1$, the patterns have two lobes having maximum intensity in + 40° and – 40° and for $ak_0 = 2$, two major and two minor lobes are observed. The major lobes have maximum intensity at + 30° and – 30°. In case of $\phi = 0$ plane, the pattern is nearly isotropic with a dip at 0° and maximum intensity at +60° and or – 60°. For $ak_0 = 1$, the pattern is same as the case of $n = 0$ with maximum intensity at + 75° and – 75°. The directions of maximum radiation for all the cases are reported in Table 1. The value of HPBW measured from the field patterns for these cases is given in Table 2.

Table 1. Direction of maximum radiation

Plane	Case I $n = 0$		Case II $n = 1$	
	$ak_0 = 1$	$ak_0 = 2$	$ak_0 = 1$	$ak_0 = 2$
$\phi = 0$	–	–	+60°, –60°	+75°, -75°
$\phi = \pi/2$	+45°, –45°	+75°, –75°	+40°, –40°	+30°, 30°

Table 2. Measured values of HPBW for four element linear array with superstrate

Plane	HPBW			
	Case I $n = 0$		Case II $n = 1$	
	$ak_0 = 1$	$ak_0 = 2$	$ak_0 = 1$	$ak_0 = 2$
$\phi = 0$	–	–	92°	major 68° minor 16°
$\phi = \pi/2$	34°	major 66° minor 18°	35°	25°

For $n = 0$ or $ak_0 = 1$ and 2, the HPBW increases for 34° to 66° along with a minor lobe of 18° in $ak_0 = 2$. In case II $n = 1$, $ak_0 = 1$ and 2, the HPBW decreases from 92° to 68° for $\phi = 0$ plane along with a minor lobe of 16°. It is observed that for $\phi = \pi/2$ plane, HPBW decreases from 35° to 25°. The calculated values of radiation conductance and directive gain calculated for $n = 0$ and 1 corresponding to $ak_0 = 1$ and 2, are reported in Table 3.

Table 3. Calculated values of directive gain and radiation conductance of four element linear array with superstrate

Properties calculated	Case I $n = 0$		Case II $n = 1$	
	$ak_0 = 1$	$ak_0 = 2$	$ak_0 = 1$	$ak_0 = 2$
Directive gain D_g (in dB's)	2 0938	2.1007	1.0258	1.3537
Radiation conductance G (in mho)	5.766×10^{-5}	5.52×10^{-4}	3.7809×10^{-4}	3.399×10^{-3}

It is observed from the table that for a higher order mode *i.e.* at $n = 0$ and 1, the antenna geometry shows higher values of radiation conductance. The directive gain of the antenna under investigation is also relatively high for higher order mode *i.e.* $ak_0 = 2$ in both cases *i.e.* $n = 0$ and 1.

Finally, it is concluded that the antenna geometry under investigation under the effect of superstrate cover, has unique radiation properties. It has been seen that the array antenna has better radiation conductance and higher directive gain in the desired direction over a single element slot antenna [7], which makes it suitable for mobile communication systems

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